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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-606

Furlable Spacecraft Antenna Development: Second Interim Report

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PREFACE

The work described in this report was performed by the Applied Mechanics Division of the Jet Propulsion Laboratory.

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ABSTRACT

Recent activities at JPL directed toward the development of large furlable spacecraft antennas using conical main reflectors are described. Development of two basic antenna configurations conceived at JPL and utilizing conical main reflectors has been pursued. A 4.3-m (14-ft)-diameter model based on the two-reflection conical-Gregorian concept and a 1.8-m (6-ft)-diameter model based on the four-reflection Quadreflex concept have been made and RF-tested.

RF gain measurements for the 4.3-m (14-ft)-diameter conical-Gregorian model were 48.83 dB at X-band (8.448 GHz) and 37.82 dB at S-band (2.297 GHz). These gains correspond to efficiencies of 53.6 and 57.5%, respectively.

RF gain measurements for the 1.8-m (6-ft)-diameter Quadreflex model were 47.59 dB at Ku-band (16.33 GHz) and 41.30 dB at X-band (8.448 GHz), corresponding to efficiencies of 58.6 and 51.5%, respectively.

I. INTRODUCTION

During the past three years development effort at JPL has been directed toward the demonstration and evaluation of two novel furlable spacecraft antenna concepts which employ conical main reflectors. These two concepts are the conical-Gregorian antenna, which involves two reflections of each ray entering or emanating from the antenna, and the Quadreflex antenna, in which each entering or emanating ray experiences four reflections.

Several 1.8-m (6-ft)-diameter antenna models based on the conical-Gregorian concept were fabricated and RF-tested to determine gain characteristics at both X-band (8.448 GHz) and Ku-band (16.33 GHz) frequencies. Development activities, analyses, and test programs leading to the successful demonstration of a furlable 1.8-m (6-ft)-diameter conical-Gregorian antenna with a lightweight spoke-supported ring-membrane conical reflector are described in Refs. 1-7.

A 0.76-m (30-in.)-diameter nonfurlable antenna model based on the Quadreflex antenna concept (Ref. 8) was fabricated and tested at Ku-band (16.33 GHz). This model and its test results are described in Ref. 6.

As indicated in Ref. 6, the results obtained from the 1.8-m (6-ft)-diameter furlable spoke-supported ring-membrane conical-Gregorian antenna and from the 0.76-m (30-in.)-diameter Quadreflex antenna model were sufficiently encouraging to warrant further development of both concepts.

The present report describes this further development work, which involved the fabrication and RF testing of a 4.3-m (14-ft)-diameter furlable spoke-supported ring-membrane conical-Gregorian antenna and a 1.8-m (6-ft)-diameter furlable spoke-supported ring-membrane Quadreflex antenna.

II. CONICAL-GREGORIAN ANTENNA

The successful demonstration of a 1.8-m (6-ft)-diameter furlable spoke-supported ring-membrane conical-Gregorian antenna proved that this concept is basically feasible. It remained to be shown, however, that this concept is feasible for larger diameter antennas as anticipated for future spacecraft. To this end, a 4.3-m (14-ft)-diameter furlable conical-Gregorian antenna was built and RF-tested at X-band (8.448 GHz) and S-band (2.297 GHz) frequencies.

The size of this antenna was chosen to be identical to that of an existing radial rib mesh paraboloidal Cassegrainian feed antenna developed for the Thermoelectric Outer-Planet Spacecraft (TOPS) study program. It was intended that RF tests would provide a direct comparison of performance characteristics of the two furlable spacecraft antenna concepts. Plans to RF-test the TOPS antenna were subsequently dropped, however, so this comparison was not obtained.

The primary objective in building and testing this antenna was to demonstrate the basic mechanical feasibility of the concept. No concerted effort was made to minimize weight or to use materials compatible with spaceflight environments.

A. Configuration

The basic geometry of the 4.3-m (14-ft)-diameter conical-Gregorian antenna is shown in Fig. 1. This geometry was established by Telecommunications Division personnel, and is based on the analysis developed by Ludwig (Ref. 5). This configuration is nearly optimum from the standpoint of aperture blockage due to the subreflector, producing a blockage based on ray optics of 21.7%.

The proper shape of the subreflector is generated by rotation about the antenna axis of a segment of a parabola. In polar coordinates (see Fig. 1), this shape is defined by (Ref. 5).

$$\rho = 2f/[1 + \cos(\beta - \theta)] \tag{1}$$

where ρ is the distance from the feed phase center to a point on the subreflector and on a ray which forms the angle θ with the antenna axis, f is the focal length of the parabola which generates the subreflector surface, and β is the angle between the axis of the generator parabola and the antenna axis. The maximum feed illumination angle subtended by the subreflector is 32 deg.

B. Design and Construction

The antenna is shown at several stages of assembly in Figs. 2-5. All major structural components are visible in Fig. 2 and consist of a hub, subreflector support truss, subreflector and forward spoke support ring, subreflector, outer main reflector ring, and forward and aft spokes.

The hub consists of a 3.8-cm (1.5-in.)-thick aluminum-core-aluminum face-sheet honeycomb plate 1.5 m (60 in.) in diameter, an inner machined-ring insert, and an outer registration ring.

The inner machined-ring insert provides a basic reference for location of the axis of the antenna, and also provides a bearing support for use in aligning the conical main reflector membrane surface (Fig. 5). The main reflector, the subreflector, and the feed support are aligned with respect to the axis of this ring insert.

The outer registration ring of the hub provides the inner registration ring for the tapes which support the conical main reflector membrane. Figure 6 illustrates the attachment of the membrane support tapes and the rear spokes to the outer edge of the hub.

The outer main reflector support ring is made of 7075-T6 aluminum alloy. It forms a flat circular annulus with an inside diameter of 4.3 m (14 ft), and has a cross section 4.45 cm wide by 0.23 cm thick (1.75 × 0.090 in.). The method used for attaching the spokes and the membrane conical reflector surface to the outer ring is shown in Fig. 7.

The spokes are attached to the outer ring through screws which provide a simple means for adjusting the length of each spoke. The outer ring was suspended and positioned approximately in its final position before attaching the membrane reflector panels. At this point the lengths of the spokes were adjusted to produce a tension of approximately 14.5 N (3.3 lb) in each lower spoke. After attaching the membrane panels, the outer ring was readjusted by changing spoke lengths to force the panel to coincide with the proper conical surface near each of the 96 spoke attachment points on the outer ring.

Note that this technique for providing a conical surface eliminates virtually all necessity for a precisely formed outer ring. A non-circular outer ring can be compensated for by deforming it out-of-plane until its inner edge coincides with the proper cone at each spoke attachment point.

The main conical reflector is formed by 17 aluminized Mylar panels 0.025 mm (0.001 in.) thick. There are 16 standard panels, each spanning 22.5 deg about the cone, and one 9.37-deg panel to make up for overlapping of panels. The Mylar panels are supported on 314 fiberglass tapes 0.64 cm wide and 0.08 mm thick (0.25 × 0.003 in.). These tapes are spaced at 3.75-deg intervals about the cone, and are attached to the hub and the outer ring through coil springs as shown in Figs. 6 and 7. These springs maintain approximately constant tensions on the tapes.

The method used to measure deviations of the main reflector surface from the proper cone is illustrated in Fig. 5. The antenna is mounted on a fixture which provides a bearing with a vertical axis on which the antenna can be rotated. A precisely ground bar is mounted on the fixture so that it forms an angle of 63 deg with the antenna axis. A micrometer head with its axis normal to this ground bar can be moved to any position along the bar. The micrometer screw is rotated until visual observation shows contact with the Mylar membrane. Variations in micrometer readings at different positions along a ray and on different rays provide direct measurements of deviations of the reflector surface from the proper conical surface.

To obtain rms surface deviation measurements, such readings were taken at three radial positions on each of 96 equally spaced rays about the antenna. After readjusting the outer ring, rms surface deviations from 0.43 mm (0.017 in.) to 0.64 mm (0.025 in.) were achieved, based on 288 such measurements.

The subreflector is an aluminum-core fiberglass-face-sheet honeycomb construction. The core has 0.64-cm (0.25-in.) hexagonal cells made of 0.038-mm (0.0015-in.)-thick aluminum, and is 1.9 cm (0.75 in.) deep. The face sheets are 0.38-mm (0.015-in.)-thick fiberglass. An aluminum stiffener ring with a tubular section 6.4-cm (2.5-in.) outer diameter and 0.81-mm (0.032-in.) wall is bonded to the outer (non-reflective) surface of the subreflector near its outer periphery.

Measurements of the inner surface shape indicate an rms deviation from the proper shape (Eq. 1) of 0.2 mm (0.008 in.).

In order to provide RF reflectivity, the inner surface of the subreflector was painted with three coats of conductive paint (Tecknit No. 72-00026). RF waveguide tests of sample coupons indicate that gain loss due to non-zero resistivity of this coating should be less than 0.05 dB.

The subreflector is supported at four points by adjustable attachments to the upper support ring, which, in turn, is attached to the hub through an eight-member (four-point to four-point) truss. The upper support ring is an annular box beam with a rectangular cross section 5.7 cm (2.25 in.) wide by 6.4 cm (2.5 in.) deep, and walls made of 0.51-mm (0.020-in.)-thick 6061-T3 aluminum sheet. An extended flange of this support ring also provides the upper attachment points for the upper spokes (Fig. 8).

The support truss members are made of 4.45-cm (1.75-in.) outside diameter fiberglass tubes with 0.51-mm (0.020-in.)-thick walls.

The lower spokes are made of 0.25-mm (0.010-in.)-diameter steel wires. The upper spokes are made of 6.4-mm (0.25-in.)-wide by 0.08 mm (0.003-in.)-thick fiberglass tapes to minimize RF blockage. Both upper and lower spokes are attached to the outer support ring through screw adjustment fixtures (Fig. 7).

C. RF Gain Measurements

The RF gain of the antenna was measured on the antenna test range at JPL. Gain measurements were made at S-band (2.297 GHz) and X-band (8.448 GHz) frequencies. Gain measurements were 37.82 dB and 48.83 dB, respectively, corresponding to efficiencies of 57.5 and 53.6%, respectively.

In order to prevent small wind loads from distorting the membrane reflecting surface, the antenna was encased in an inflated cover which, in effect, provides a close-fitting radome. The enclosed antenna is shown mounted on the positioner in Figs. 9, 10, and 11.

The wind protection cover is formed by two conical membranes with a tubular aluminum support ring located at the intersection of the two cones. The rear cone is made of vinyl-coated nylon fabric, and the forward cone is made of 0.08-mm (0.003-in.)-thick Mylar to minimize RF losses. The forward and rear cones, in effect, constitute two sets of spokes which support the aluminum tube in much the same manner that the outer ring of the antenna is supported. The vertex of the forward cone is supported by a truss structure (Fig. 8) which transmits the wind cover loads to the subreflector support truss.

The wind protection cover is pressurized to approximately 0.012 N/cm^2 (0.018 psi) by using a shop-type vacuum cleaner as a blower. The vacuum cleaner is attached to the antenna positioner (Fig. 11).

III. QUADREFLEX ANTENNA

A. Configuration

The geometry of the 1.8-m (6-ft)-diameter Quadreflex antenna is shown in Fig. 12. This configuration was established on the basis of ray optics, the basic principles of the Quadreflex antenna (Ref. 8), a minimum urn subreflector diameter of ten wavelengths at Ku-band (16.33 GHz), and minimum blockage due to the subreflector. The resulting blockage due to the subreflector is 2.1%. The location of the feed center (Fig. 12) was established by the maximum illumination angle (22 deg) of the feed used.

B. Design and Construction

The completed antenna is shown in Figs. 13-17. The basic design features of the conical main reflector are identical to those described above for the 4.3-m (14-ft)-diameter conical-Gregorian antenna. It is made of 16 tape-supported aluminized Mylar panels (0.025 mm (0.001 in.) thick). The support tapes are connected through springs to an inner hub at the base of the antenna and to the outer ring (Figs. 14 and 17).

The outer ring is supported by 40 pairs of spokes. The lower (non-illuminated) spokes are steel wires and the upper (illuminated) spokes are fiberglass tapes.

The urn subreflector is machined from aluminum. The rms deviation of the urn surface from the proper shape is less than 0.08 mm (0.003 in.). The urn subreflector is the major structural element between the antenna base and the elliptical subreflector. It also provides the structural support for the feed.

A more nearly flight-like urn subreflector was fabricated of graphite-epoxy composite. This alternate urn subreflector is shown in Figs. 18 and 19. The measured rms deviation of the surface of this subreflector is 0.08 mm (0.003 in.). After completion of tests to measure static and dynamic structural properties, this subreflector will be installed in the 1.8-m (6-ft)-diameter Quadreflex antenna, and RF gain measurements will be obtained. Details of the design, fabrication and inspection of this graphite-epoxy urn subreflector are reported separately in Ref. 9.

The elliptical subreflector is machined aluminum. The rms deviation of its reflecting surface from the proper surface is less than 0.08 mm (0.003 in.). This subreflector is supported from the upper end of the urn subreflector by three struts. These struts are fiberglass-epoxy except in the vicinity of the intermediate focal ring, where thin steel blades are used to minimize RF blockage.

The upper ends of the fiberglass spokes are attached to an aluminum ring approximately 30 cm (12 in.) above the elliptical subreflector. This upward displacement of the upper spoke support was required to increase the spoke angle and thus decrease the spoke tensions required to position the outer ring.

Figures 16 and 17 show the antenna on the cone measurement and alignment fixture. The technique used for measuring and aligning the conical surface is the same as described above for the 4.3-m (14-ft)-diameter conical-Gregorian antenna. The measured rms deviation of the surface from the proper cone was between 0.23 mm (0.009 in.) and 0.46 mm (0.018 in.).

C. RF Gain Measurements

RF gain of this antenna was measured by the JPL Telecommunications Division on the JPL Antenna Test Range. Maximum gain at Ku-band (16.33 GHz) was 47.59 dB, corresponding to an efficiency of 58.6%. At X-band (8.448 GHz) the gain was 41.30 dB, for a corresponding efficiency of 51.5%.

IV. CONCLUSIONS AND FUTURE EFFORTS

RF testing of a 4.3-m (14-ft)-diameter conical-Gregorian antenna and a 1.8-m (6-ft)-diameter Quadreflex antenna has provided further confirmation of the basic feasibility of these concepts. It has been shown that large lightweight conical reflectors based on the spoke-supported ring-membrane concept can be fabricated and adjusted to provide reflecting surfaces precise enough for relatively efficient operation at frequencies up to X-band.

It remains to be shown that antenna systems based on these concepts and capable of satisfying future spacecraft mission requirements can be made. In particular, it has not been demonstrated that such antennas can be designed to provide the required surface accuracy for long periods of time (several years) and when subjected to severe vibration, thermal, and radiation environments anticipated for future spaceflight missions.

Future development effort will be directed toward solving the problems associated with producing large flightworthy conical antennas. Remaining major problem areas include the design of furling and launch restraint systems, automatic unfurling schemes, and the incorporation of thermally stable and spaceworthy materials.

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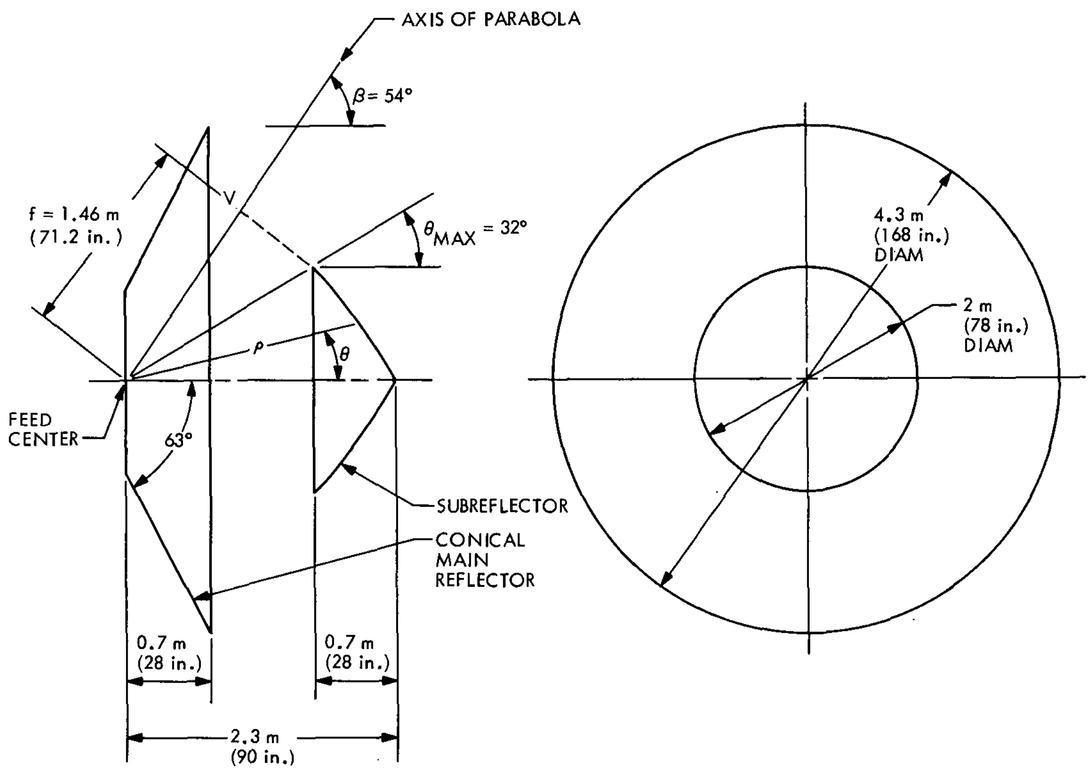

Fig. 1. Geometry of 4.3-m (14-ft)-diameter conical-Gregorian antenna

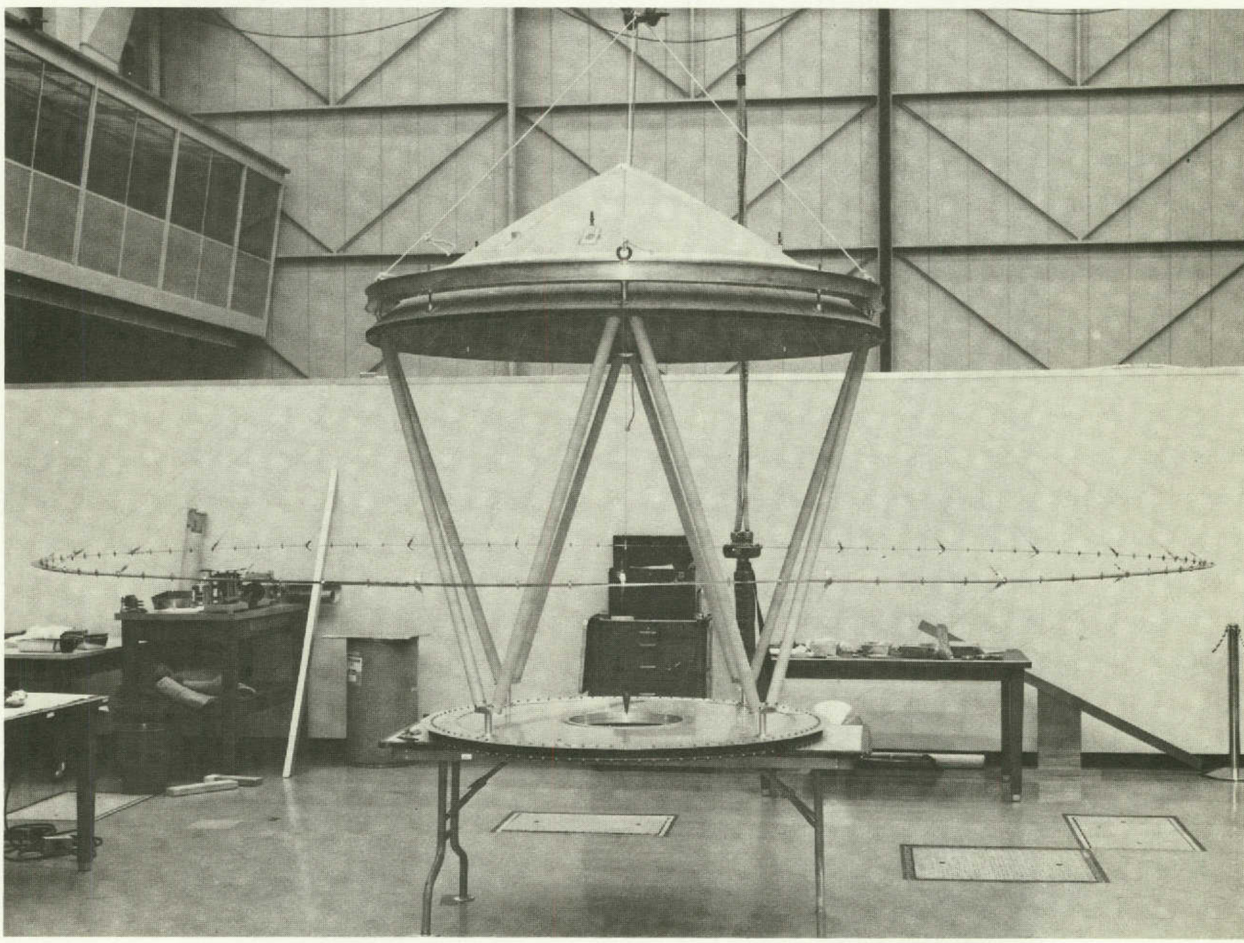

Fig. 2. 4.3-m (14-ft)-diameter conical-Gregorian antenna during assembly

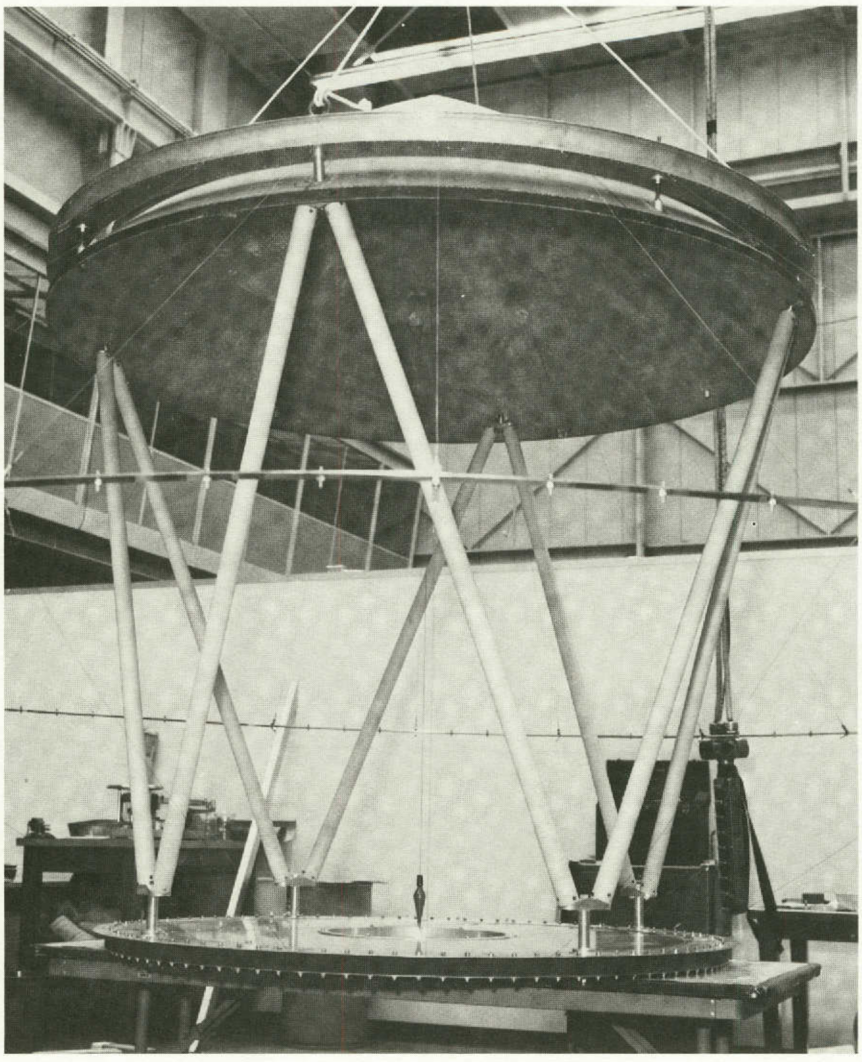

Fig. 3. Underside of 4.3-m (14-ft)-diameter conical-Gregorian antenna subreflector

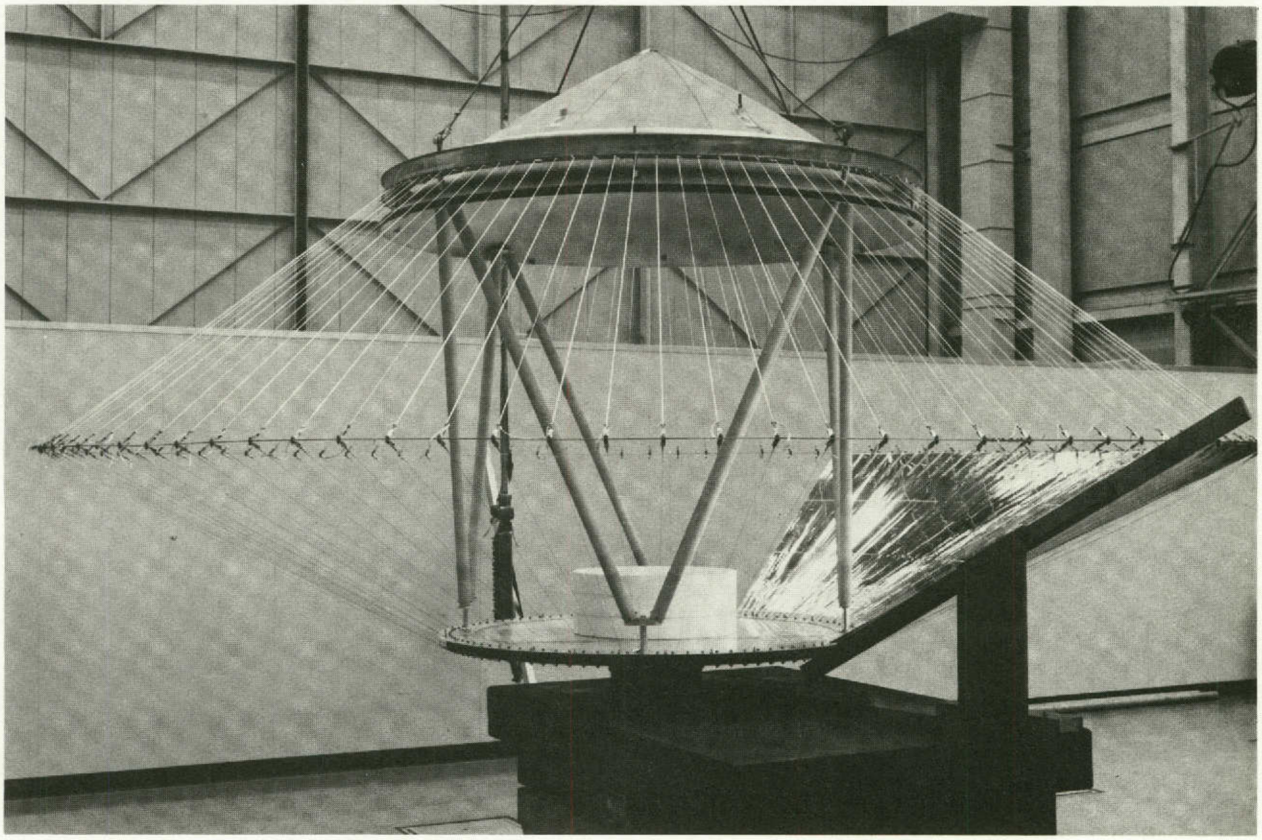

Fig. 4. 4.3-m (14-ft)-diameter conical-Gregorian antenna showing partial cone

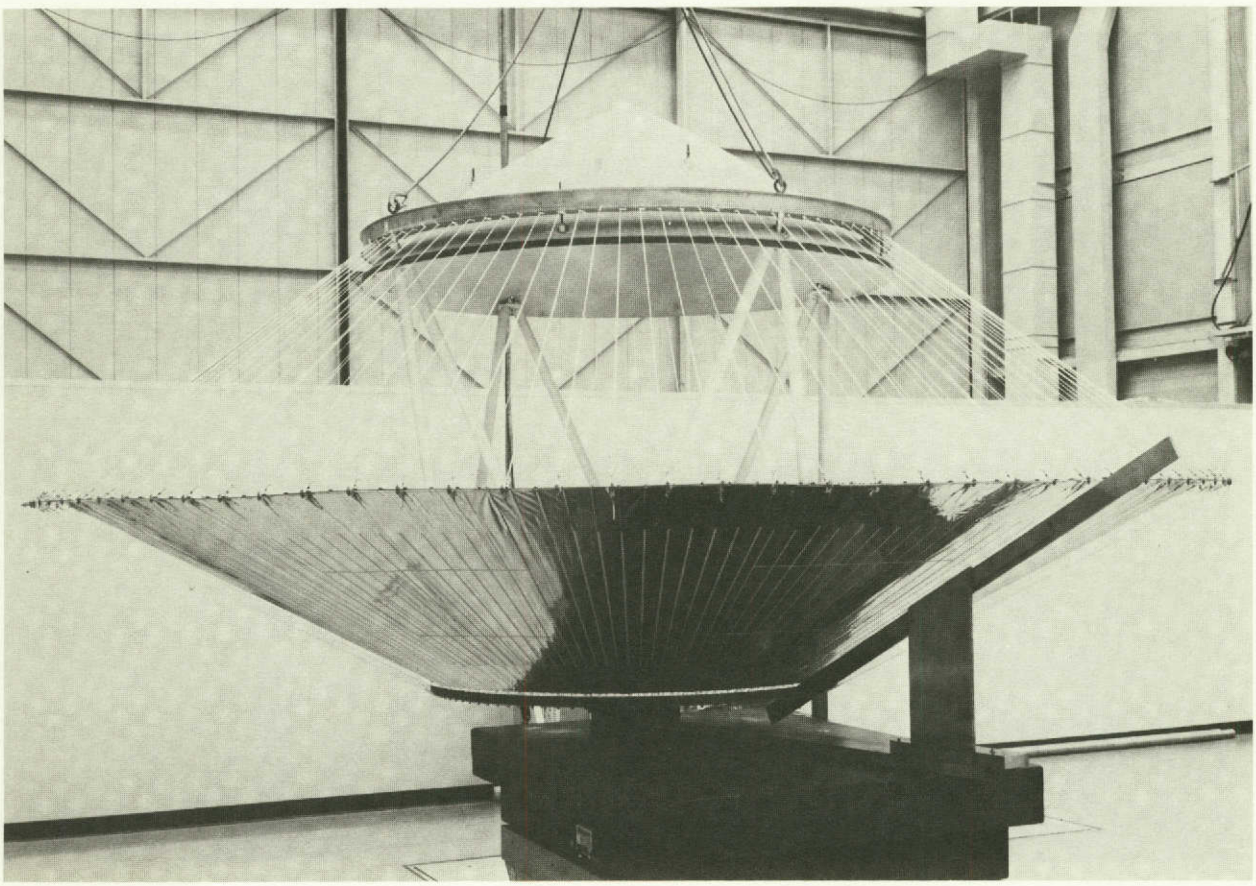

Fig. 5. Assembled 4.3-m (14-ft)-diameter conical-Gregorian antenna

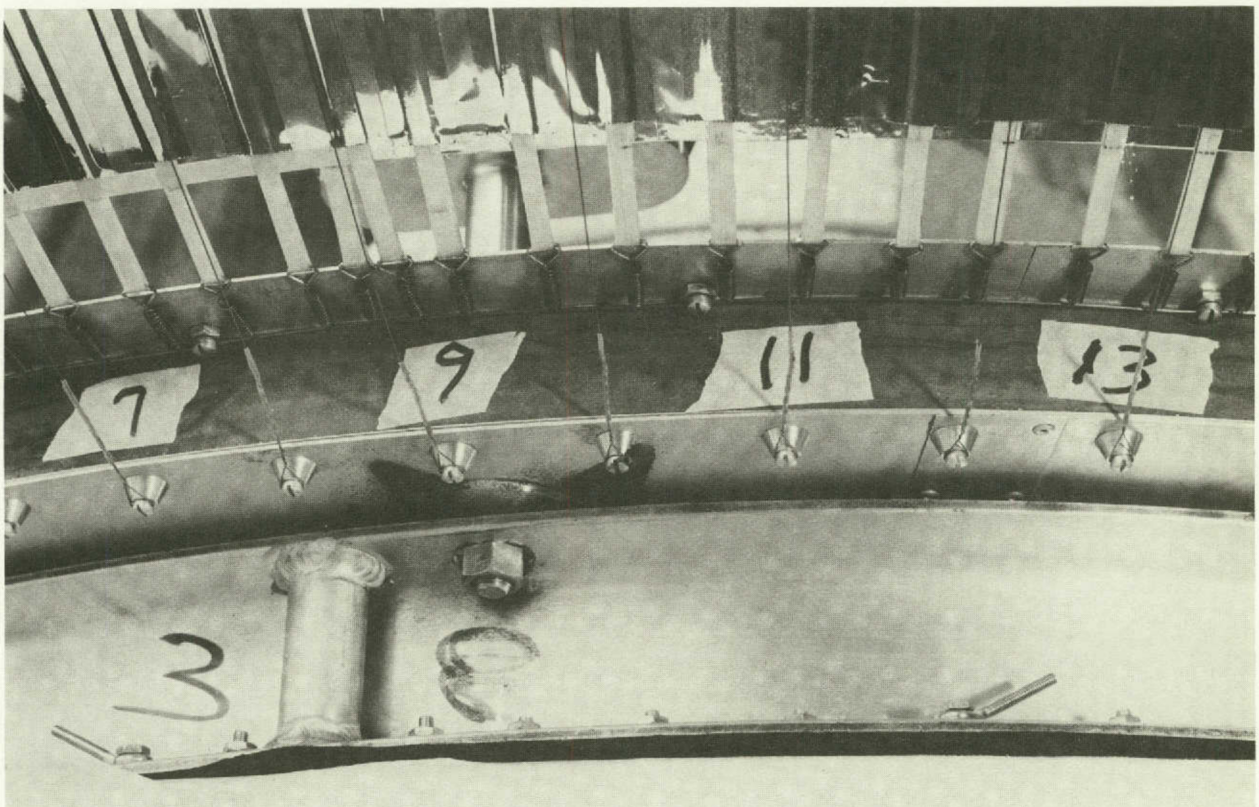

Fig. 6. Attachment of rear spokes and membrane support tapes to the hub

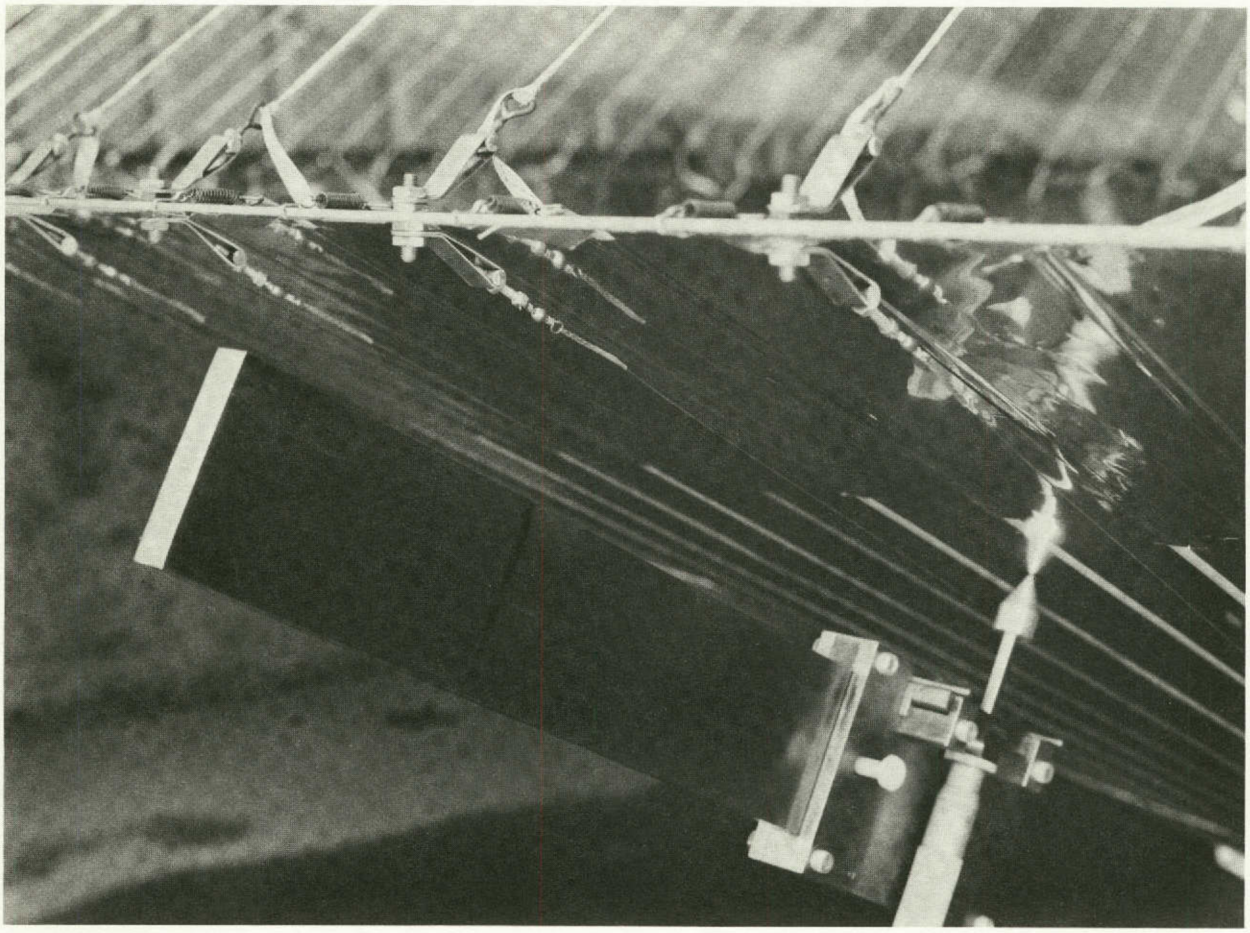

Fig. 7. Attachment of spokes and membrane support tapes to the outer ring

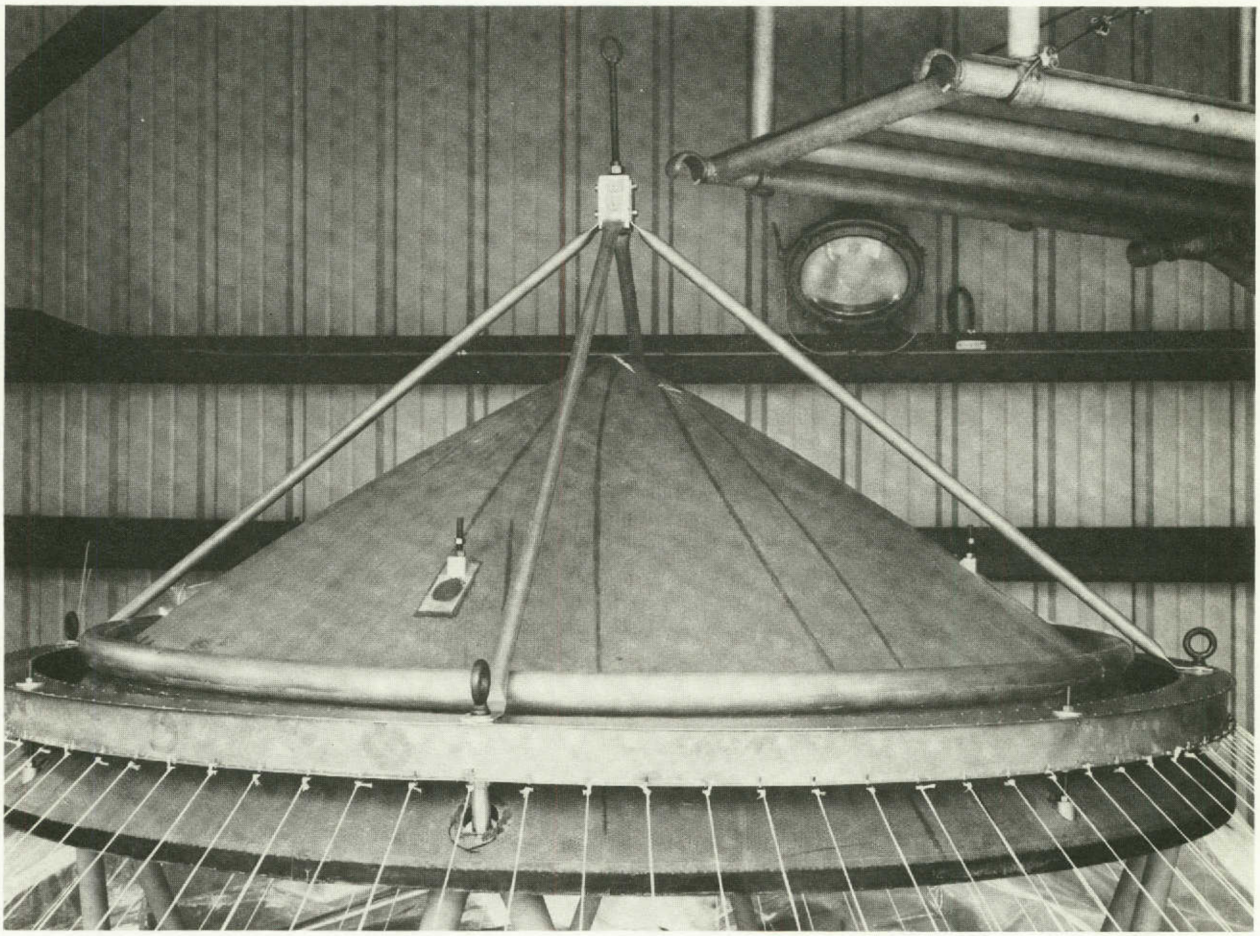

Fig. 8. Attachment of upper spokes to subreflector support ring

Fig. 9. Front view of 4.3-m (14-ft)-diameter conical-Gregorian antenna in wind protection cover

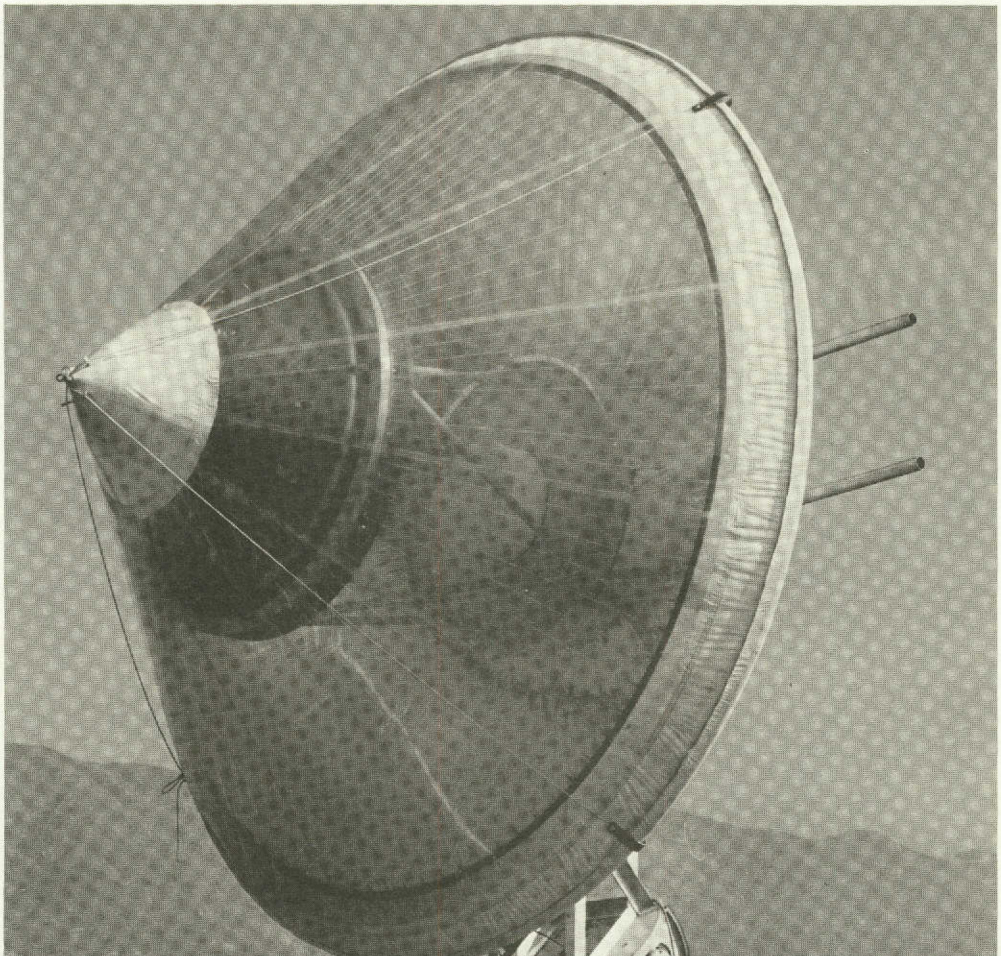

Fig. 10. Side view of 4.3-m (14-ft)-diameter conical-Gregorian antenna in wind protection cover

Fig. 11. Rear view of 4.3-m (14-ft)-diameter conical-Gregorian antenna in wind protection cover

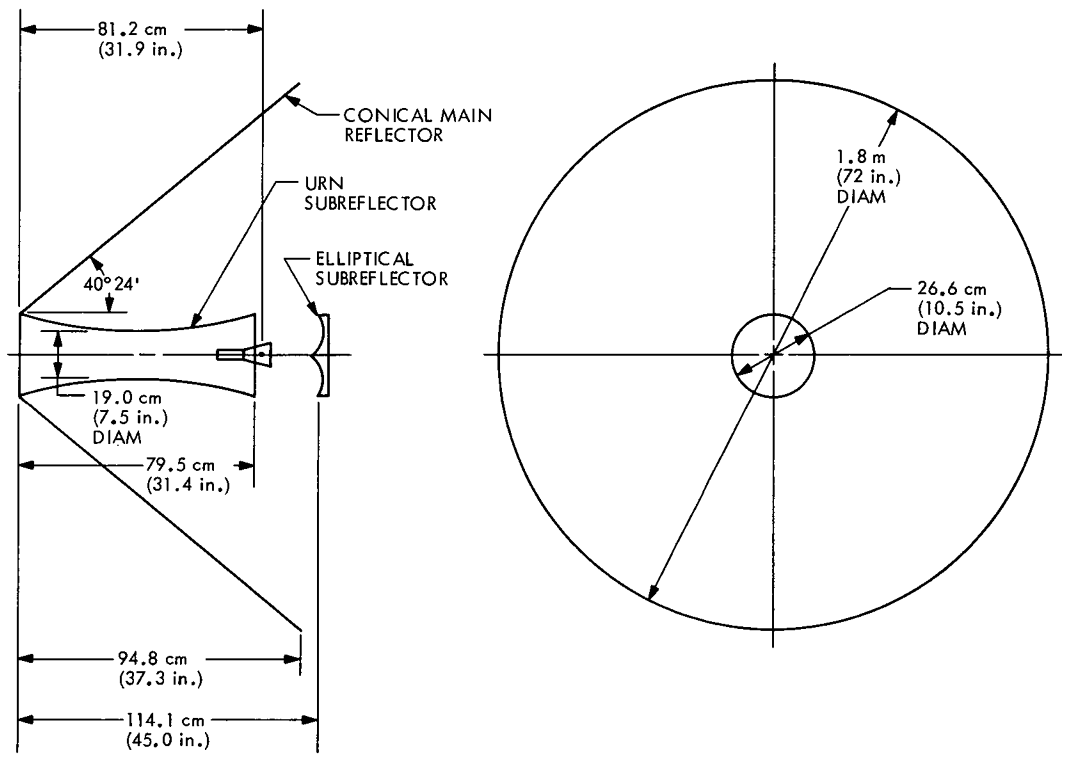

Fig. 12. Geometry of 1.8-m (6-ft)-diameter Quadreflex antenna

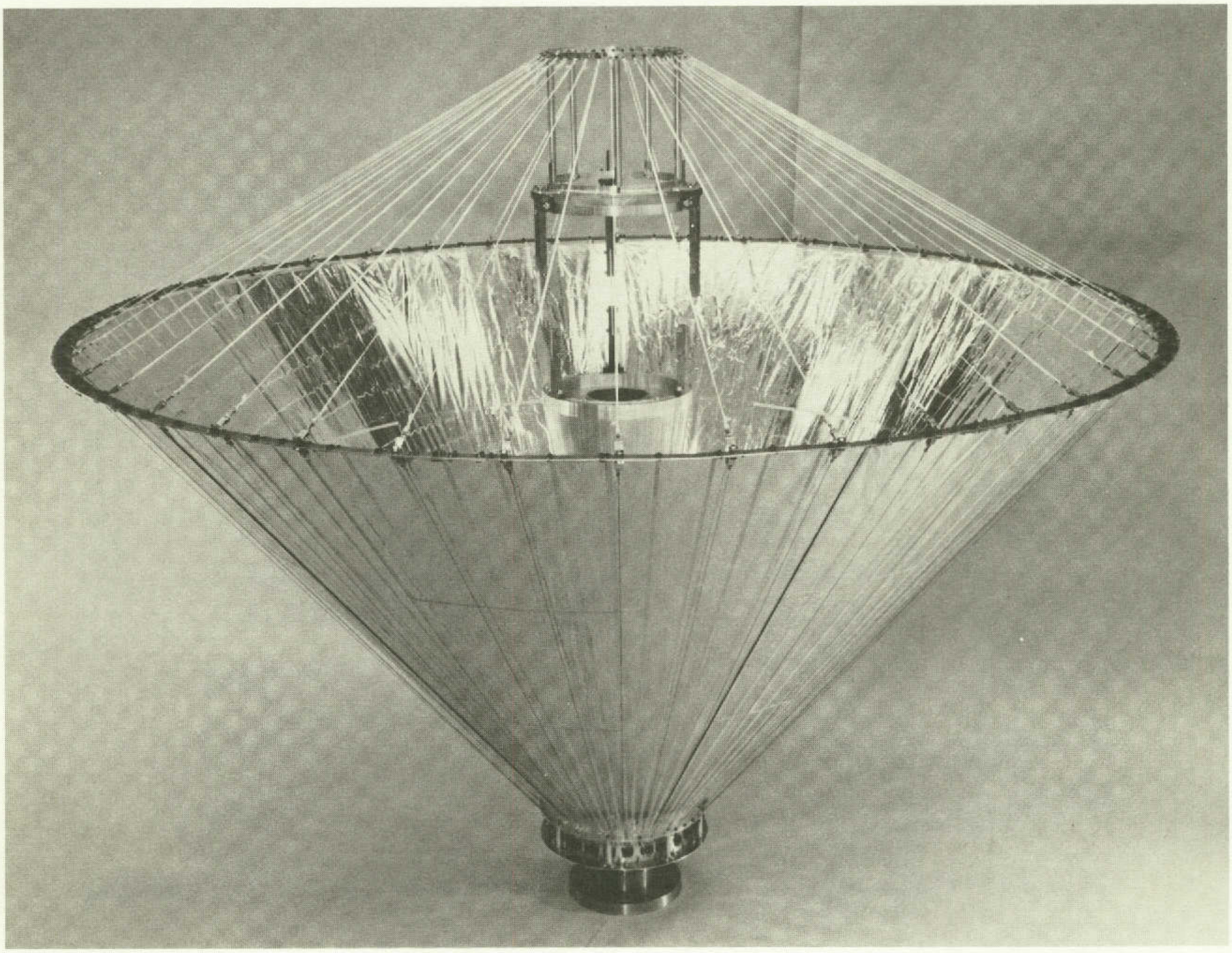

Fig. 13. 1.8-m (6-ft)-diameter Quadreflex antenna

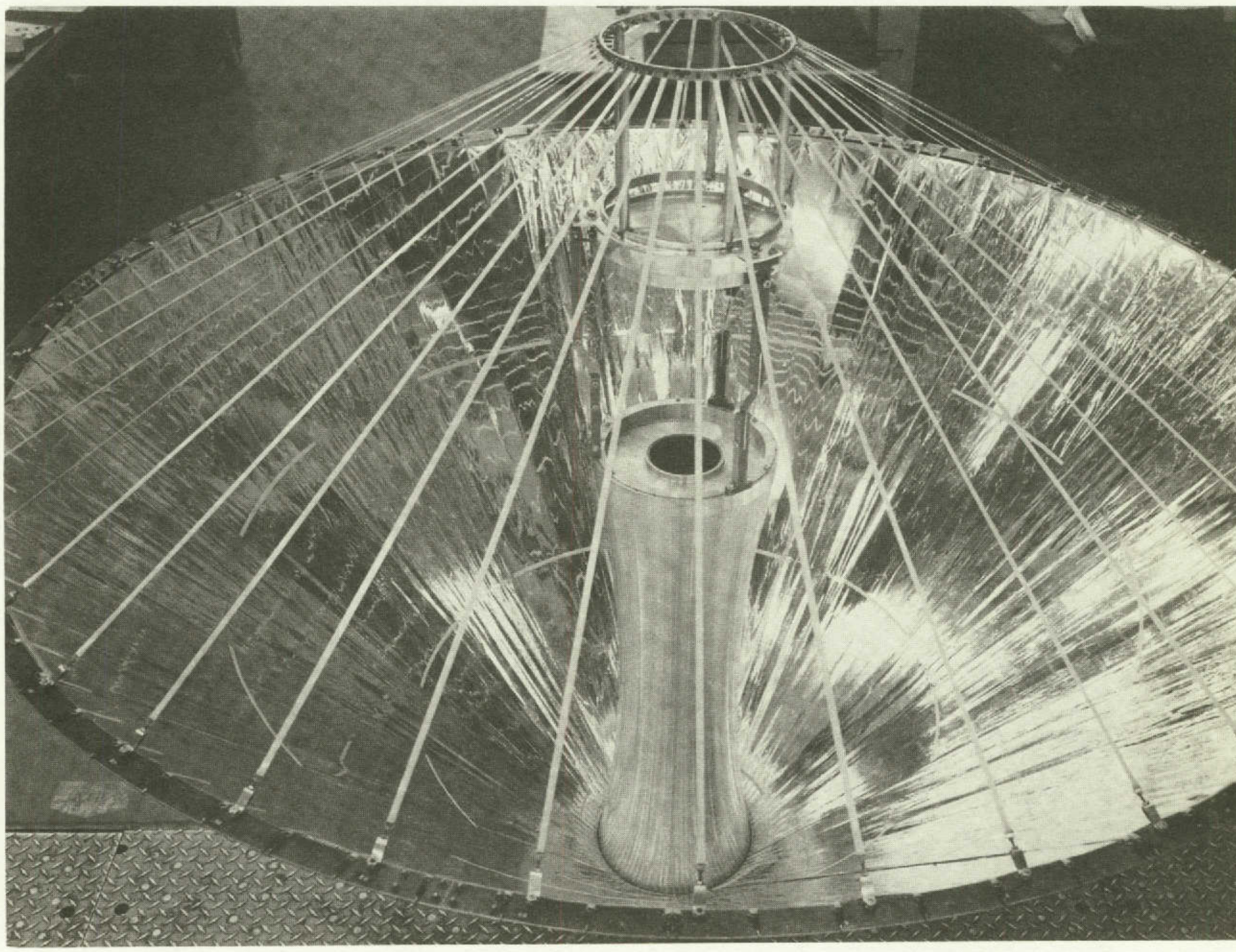

Fig. 14. 1.8-m (6-ft)-diameter Quadreflex antenna showing subreflectors

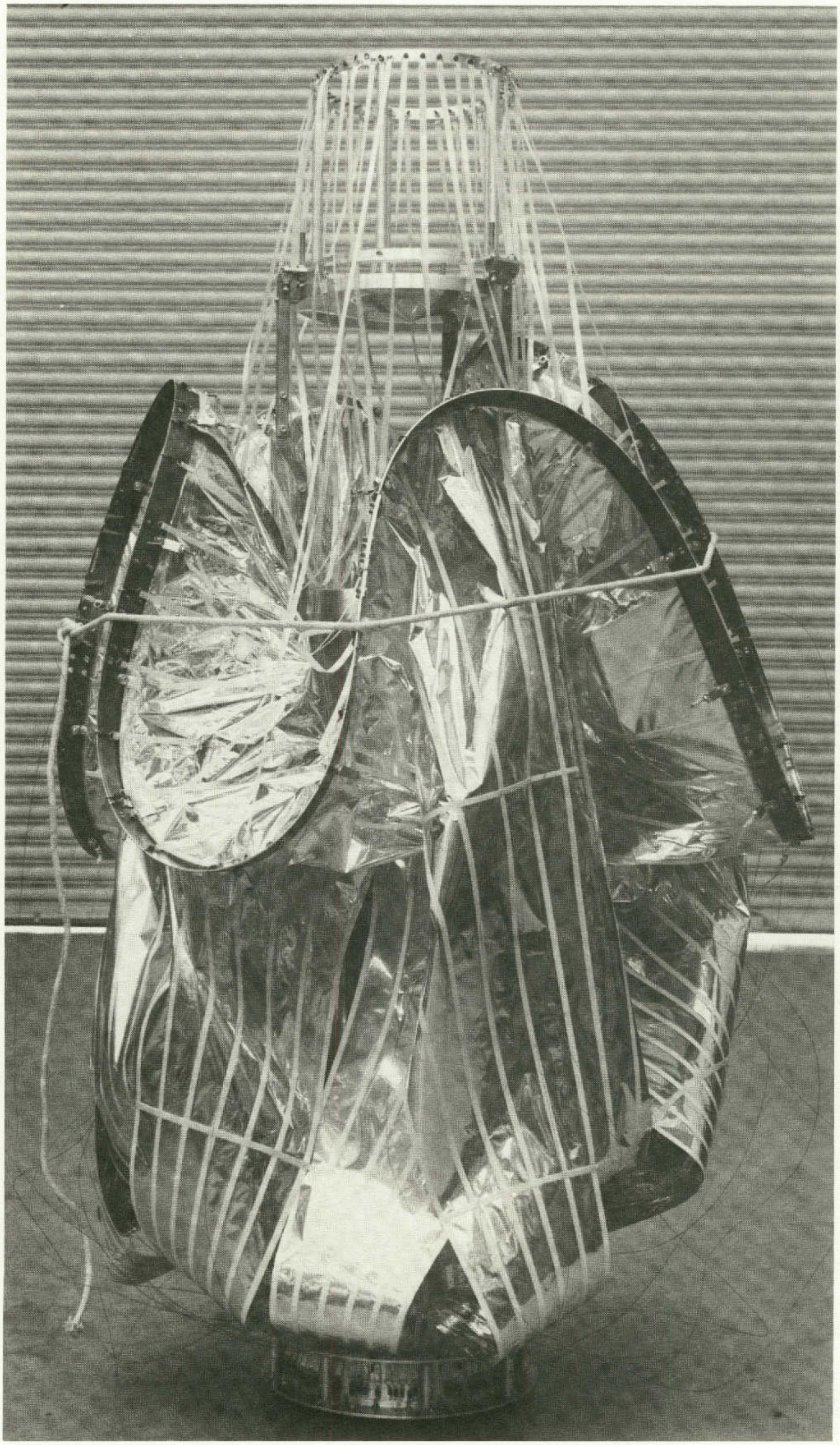

Fig. 15. Furled 1.8-m (6-ft)-diameter Quadreflex antenna

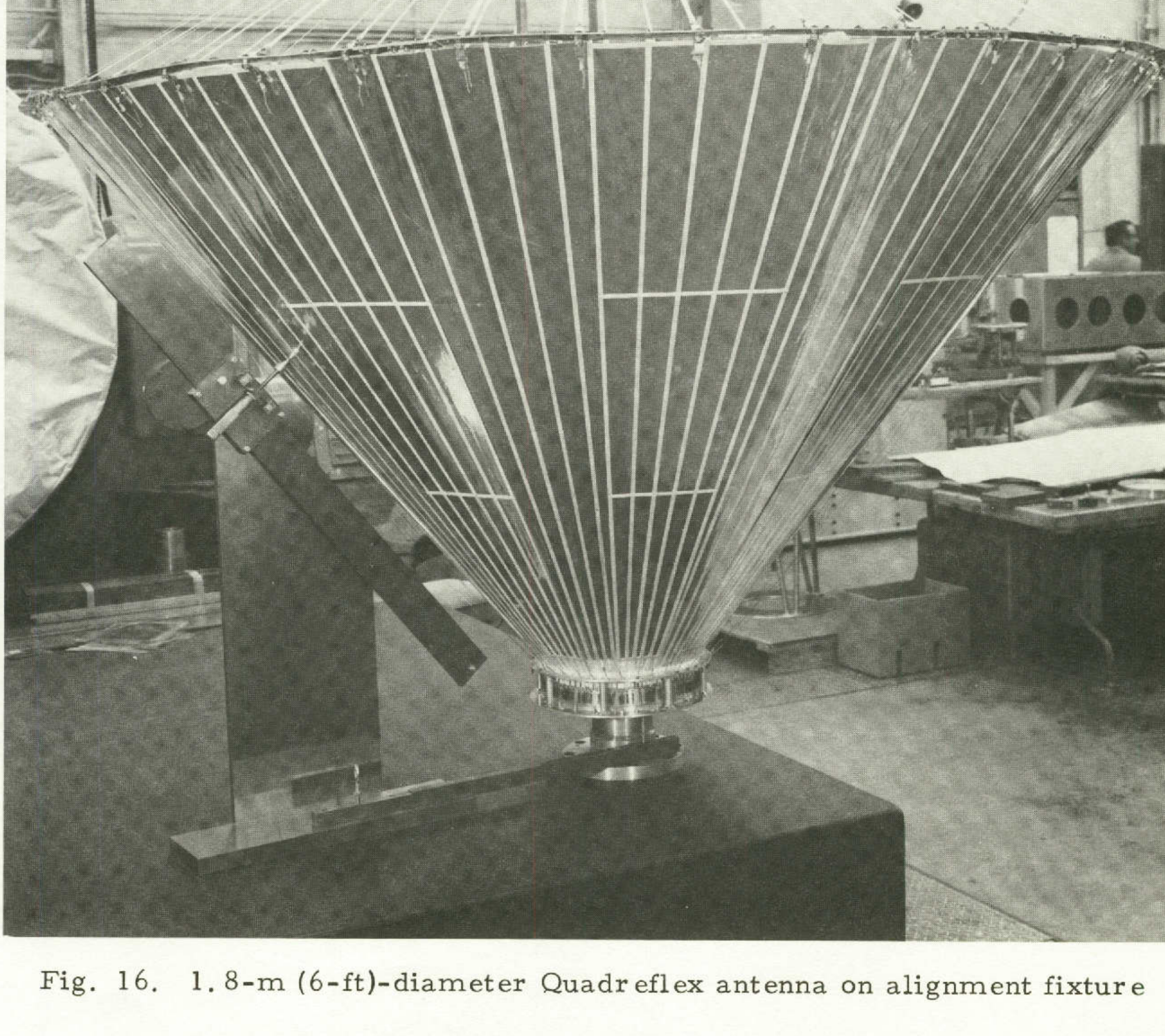

Fig. 16. 1.8-m (6-ft)-diameter Quadreflex antenna on alignment fixture

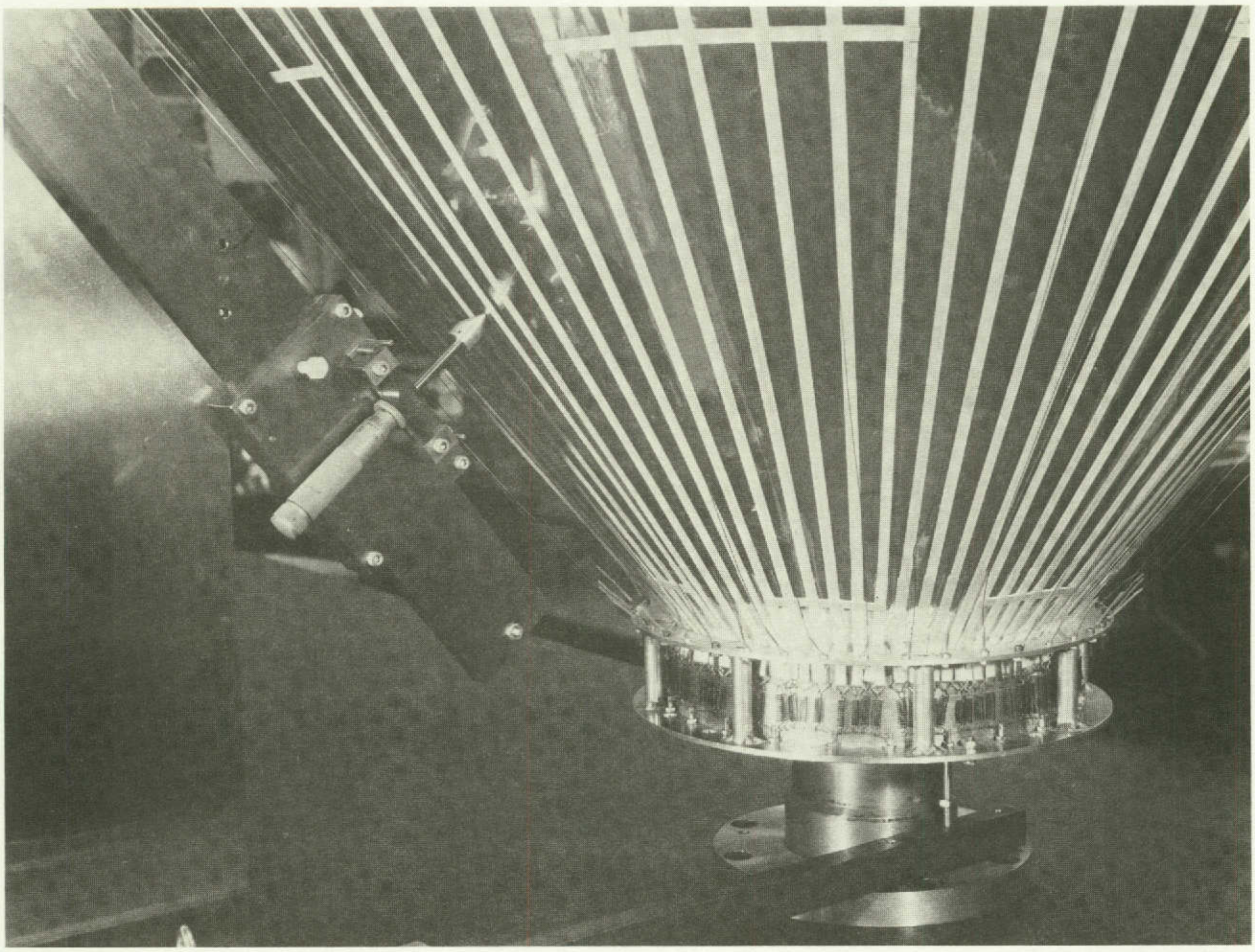

Fig. 17. 1.8-m (6-ft)-diameter Quadreflex antenna measurement fixture

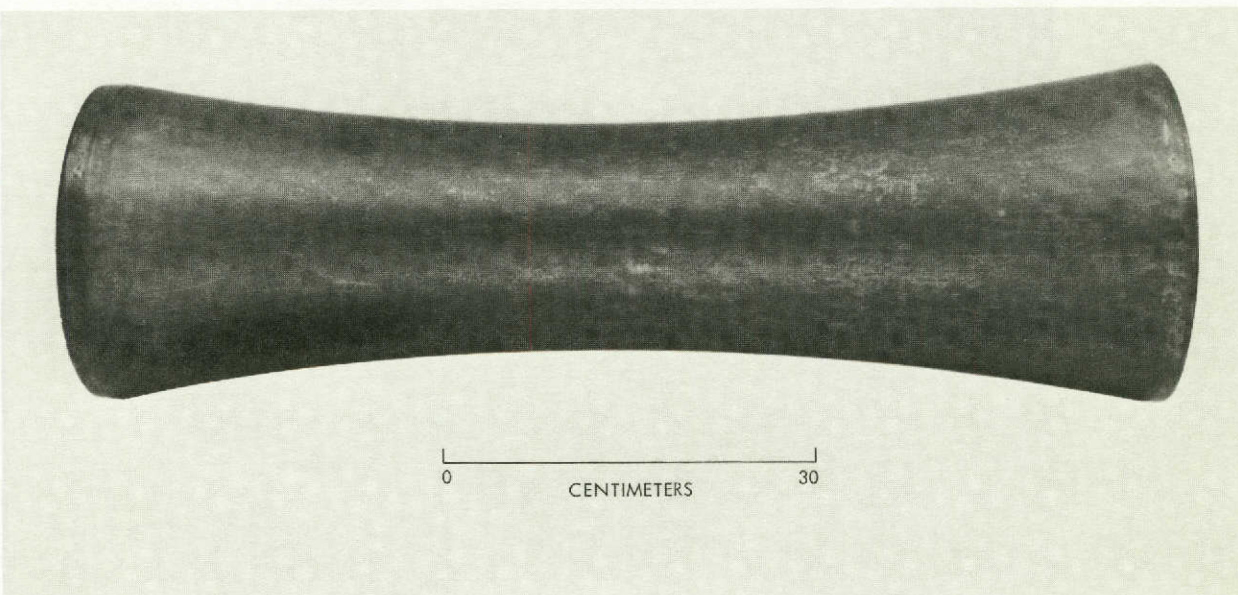

Fig. 18. Graphite-epoxy urn subreflector

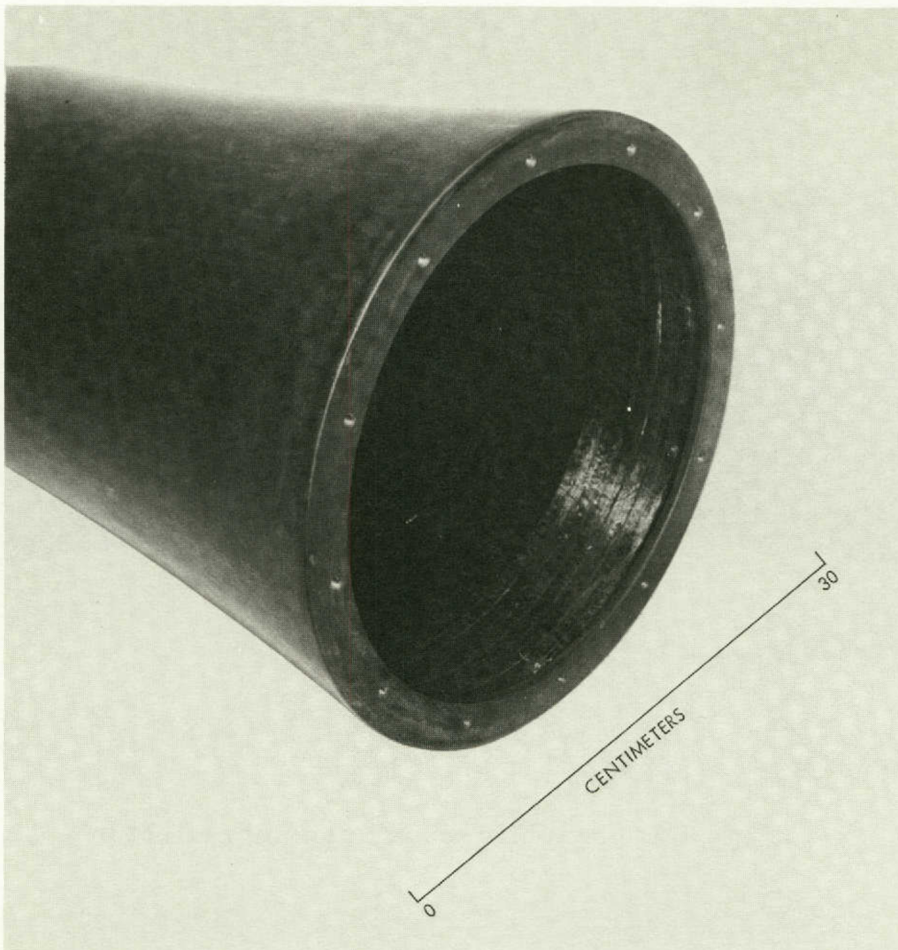

Fig. 19. End view of graphite-epoxy urn subreflector

NASA — JPL — Coml., L.A., Calif.